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(54) X-RAY TUBE

(71) Applicants: **Futaba Corporation**, Mobara-shi, Chiba (JP); **Hamamatsu Photonics Kabushiki Kaisha**, Hamamatsu-shi, Shizuoka (JP)

(72) Inventors: **Akira Matsumoto**, Mobara (JP); **Kiyoyuki Deguchi**, Mobara (JP); **Yoshihisa Marushima**, Mobara (JP); **Yuuichi Kogure**, Mobara (JP); **Kazuhito Nakamura**, Mobara (JP); **Tomoyuki Okada**, Hamamatsu (JP); **Toru Fujita**, Hamamatsu (JP); **Tatsuya Nakamura**, Hamamatsu (JP)

(73) Assignee: **FUTABA CORPORATION**, Higashi-Ku, Hamamatsu-Shi, Shizuoka (JP)

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H01J 35/18 (2006.01)

(52) **U.S. Cl.**
CPC ***H01J 35/16*** (2013.01); ***H01J 35/18*** (2013.01); *H01J 2235/087* (2013.01); *H01J 2235/168* (2013.01)

(58) **Field of Classification Search**
CPC H01J 35/04; H01J 35/045; H01J 35/14; H01J 35/16; H01J 35/18; H01J 2235/087; H01J 2235/165; H01J 2235/168
USPC 378/121, 137, 138, 140
See application file for complete search history.

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Primary Examiner — Allen C. Ho
(74) *Attorney, Agent, or Firm* — Quarles & Brady LLP

(57) **ABSTRACT**

An X-ray tube includes a radiopaque substrate including a window portion, an X-ray transmission window closing the window portion, an X-ray target provided at the window portion from an inner surface side of the substrate, a highly-evacuated container portion attached to the inner surface of the substrate, a cathode, a first control electrode and a second control electrode provided inside the container portion. A shielding electrode is provided at the inner surface of the substrate so as to surround the window portion. Electrons collide with the X-ray target to generate X-rays. Electrons reflected on the X-ray target between the shielding electrodes are absorbed by the shielding electrodes, so an inner surface of the container portion is not charged. The electron emission from the cathode is not affected by the reflected electrons, so a change in target current is small, and thus X-rays of substantially constant intensity can be radiated.

2 Claims, 6 Drawing Sheets

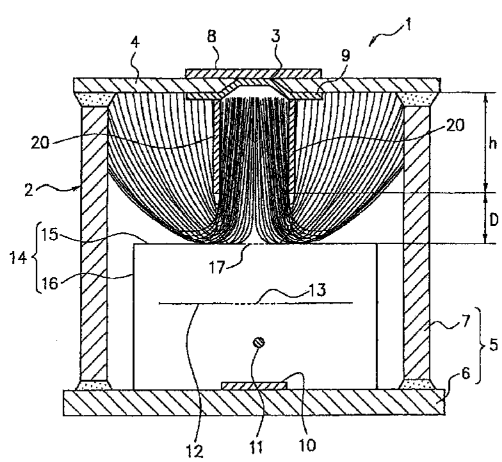

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FIG. 1

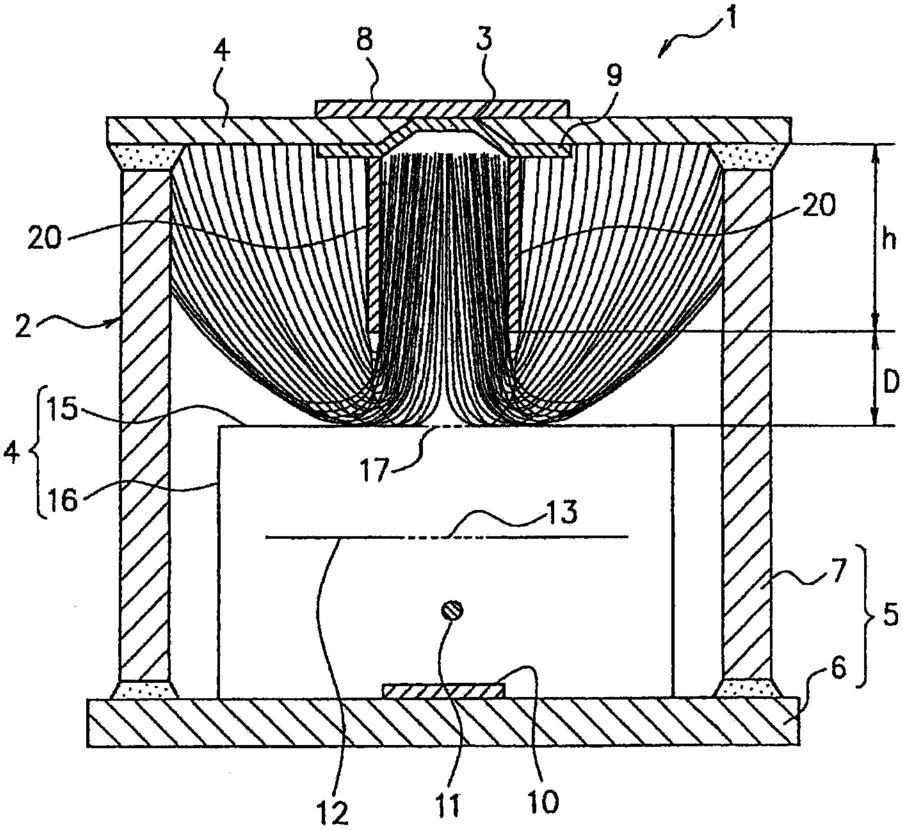
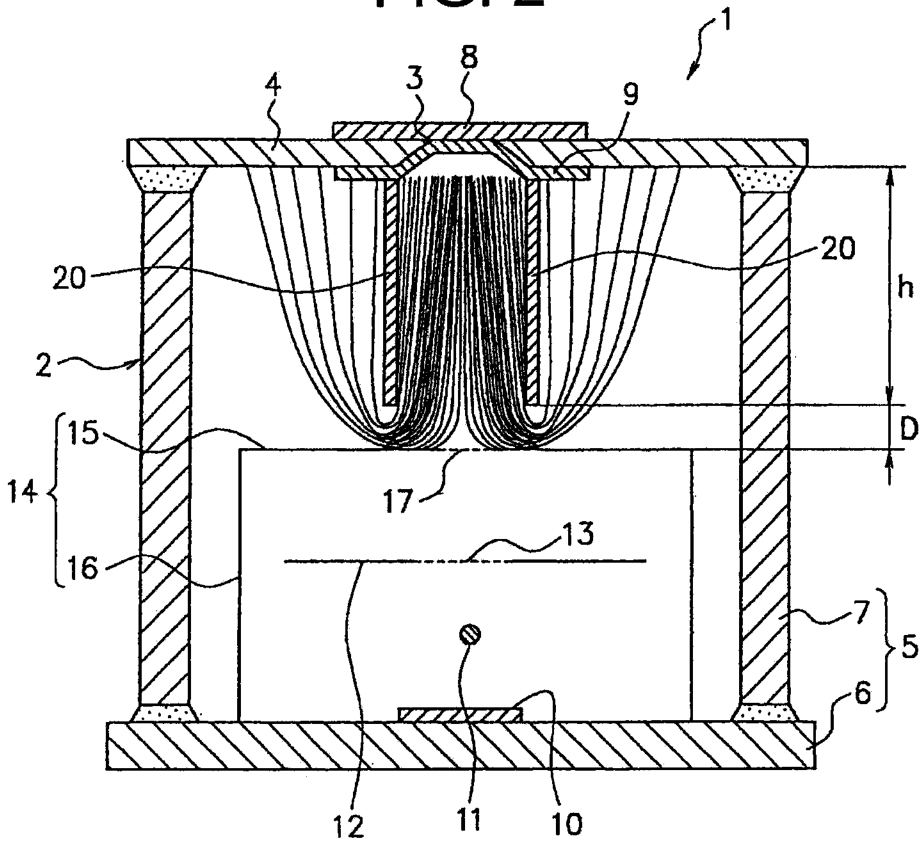


FIG. 2


1
4
3
8
9
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h
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11
10

FIG. 3

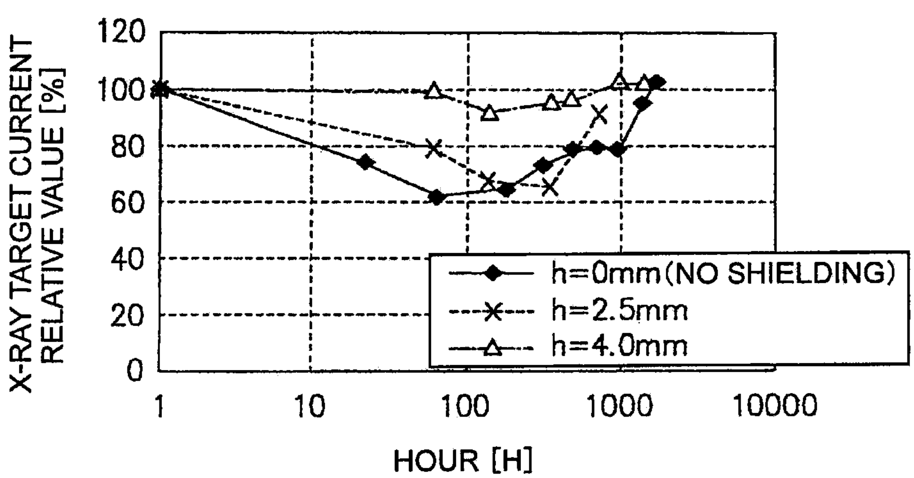

X-RAY TARGET CURRENT
RELATIVE VALUE [%]
120
100
80
60
40
20
0
1
10
100
1000
10000
HOUR [H]
h=0mm(NO SHIELDING)
h=2.5mm
h=4.0mm

FIG. 4 PRIOR ART

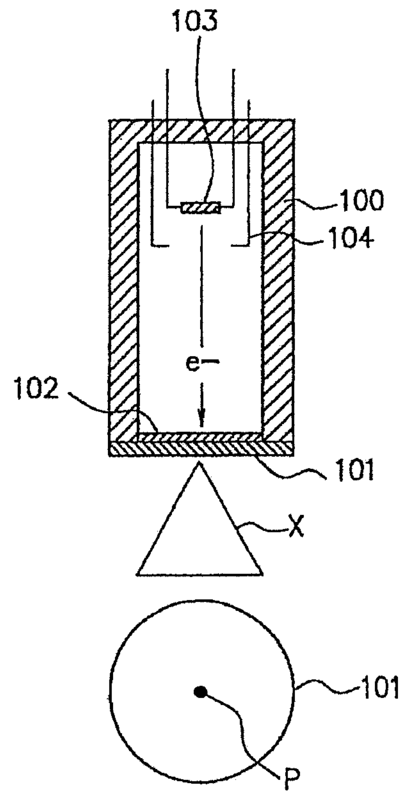


FIG. 5 PRIOR ART

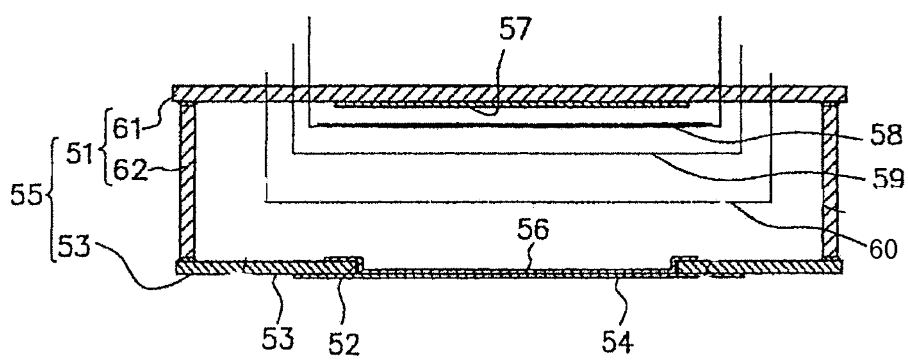


FIG. 6 PRIOR ART

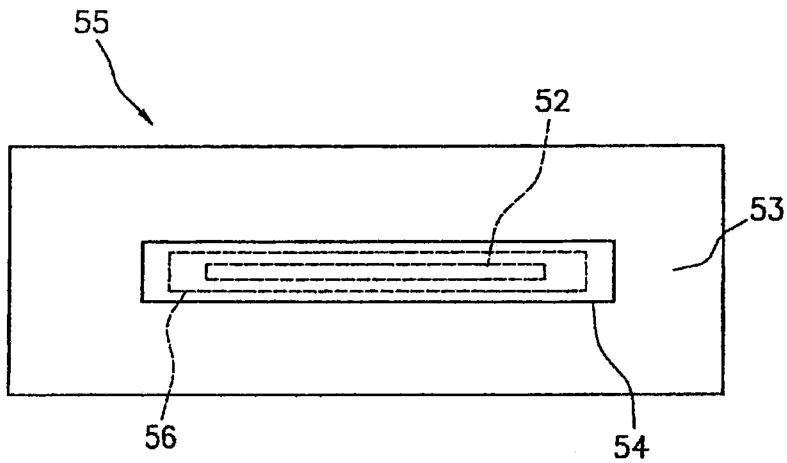


FIG. 7 PRIOR ART

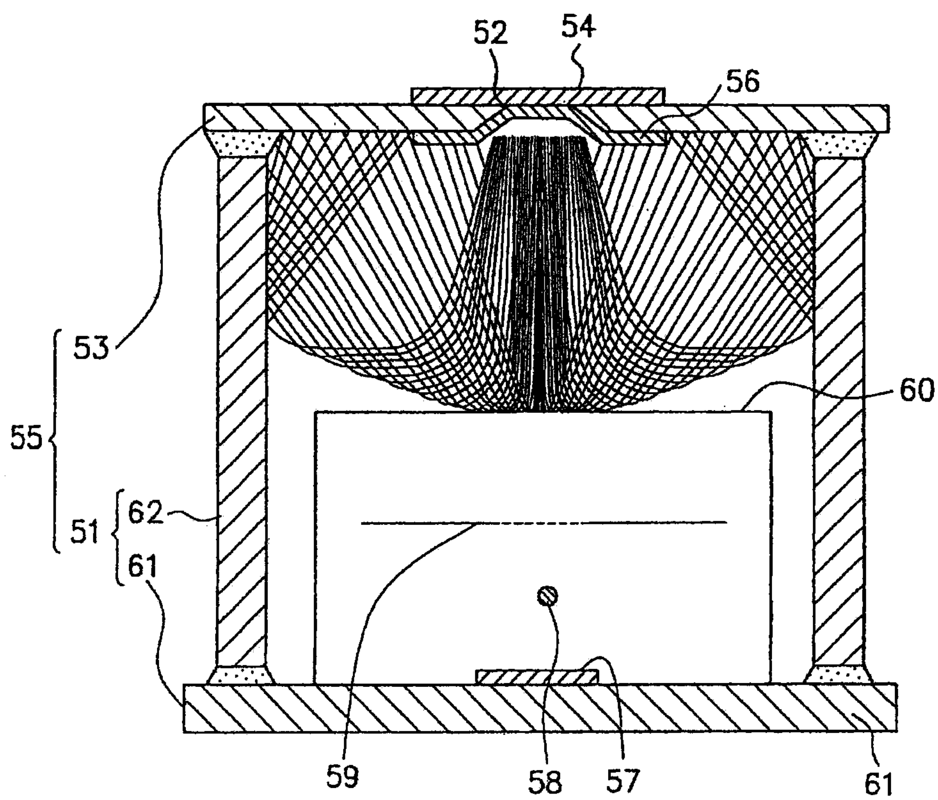


FIG. 8 PRIOR ART

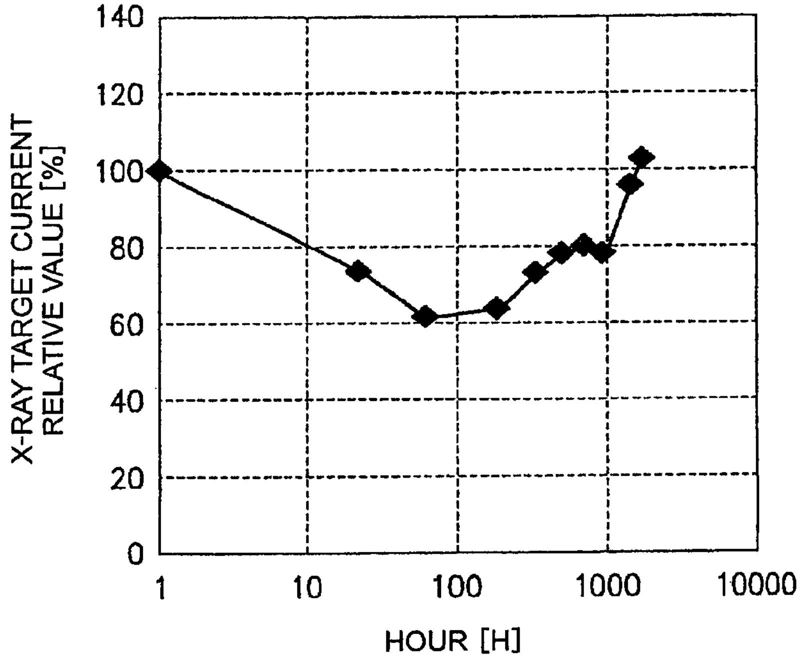


FIG. 9 PRIOR ART

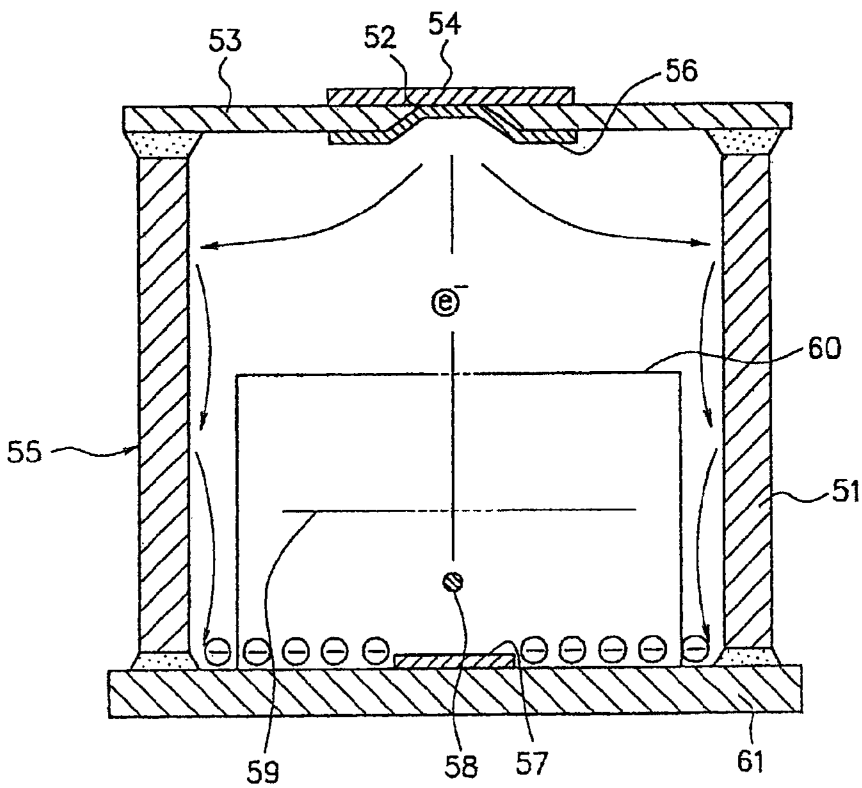
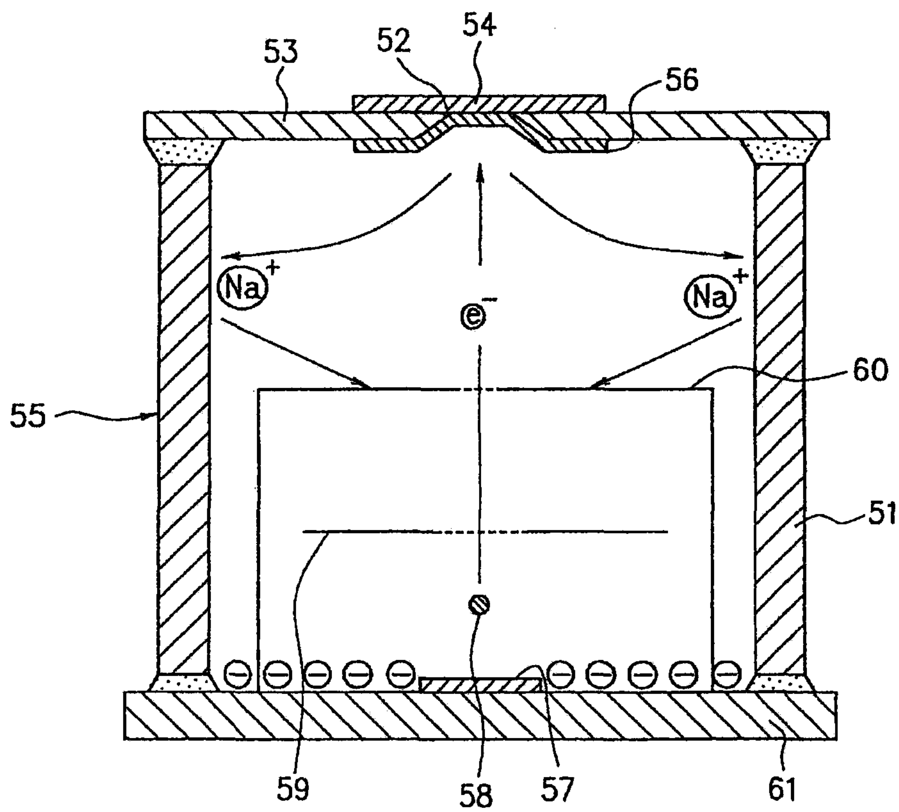


FIG. 10 PRIOR ART



X-RAY TUBE

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority from Japanese Patent Application No. 2012-220583 filed on Oct. 2, 2012, the contents of which are hereby incorporated by reference.

TECHNICAL FIELD

The present invention relates to an X-ray tube arranged to emit electrons from an electron source located on an inside of a package in a high-vacuum state, make the electrons collide with an X-ray target and radiate X-rays emitted from the X-ray target to outside through an X-ray transmission window. More specifically, the present invention relates to the X-ray tube which can prevent destabilization of operating characteristics caused by scattering, in the package, of the electrons which were reflected at the X-ray target.

BACKGROUND ART

Patent Literature 1 mentioned below discloses an X-ray generator for generating ion gas by irradiating air with X-rays. An X-ray tube used in this X-ray generator includes a main body which is a cylindrical package (or bulb). On the inside of the package, electrons emitted from a filament are focused by a focus and are collided with an X-ray target, thereby generating X-rays. The X-rays then pass through an output window (i.e. an X-ray transmission window) and exit from the package to the outside.

FIG. **4** shows a cross-sectional view of an X-ray tube which is similar to the X-ray tube of Patent Literature 1 mentioned above and which is a so-called circular-tube-type X-ray tube (hereinafter called "circular X-ray tube") having a main body which is a cylindrical package **100** made of glass. The cylindrical package **100** has a circular opening portion at its one end face. This opening portion is closed by an X-ray transmission window **101** made of a beryllium film so that the inside of the cylindrical package **100** is maintained in a high-vacuum state. On the inside of the cylindrical package **100**, an X-ray target **102** is provided on an inner surface of the X-ray transmission window **101**. Also, a cathode **103** as an electron source and a control electrode **104** are provided on the side of the other end face of the cylindrical package **100**. The electrons emitted from the cathode **103** are accelerated by the control electrode **104**, focused and collided with the X-ray target **102**, thereby radiating the X-rays from the X-ray transmission window **101** to the outside of the cylindrical package **100**. In FIG. **4**, the X-rays radiated through the X-ray transmission window **101** to the outside of the cylindrical package **100** are indicated by a reference sign X, and a center of the emission of the X-rays at the X-ray transmission window **101** is indicated by a reference sign P.

CITATION LIST

Patent Literature 1: Japan Patent Application Publication No. 2005-116534

SUMMARY OF THE INVENTION

However, the conventional X-ray tube shown in FIG. **4** has a problem as described below. That is, in the conventional X-ray tube, the electron beam from the cathode **103** is narrowed down into a beam, providing a dot-like X-ray radiation

in which the X-rays spread radially with a center P at which the electron beam had collided with the X-ray target **102** (in FIG. **4**, the center is indicated with the reference sign P), and thus the X-rays spread conically after exiting through the X-ray transmission window **101** (as shown in FIG. **4** with the reference sign X). Thus, the effective irradiation area is narrow with respect to the size of an irradiated subject. Therefore, when using such circular X-ray tube having the narrow irradiation area, it is necessary to use many X-ray tubes arranged next to each other to irradiate a wide region with the X-rays, causing an increase in the facility cost and causing a maintenance problem.

For example, to irradiate a wide region, the X-rays may be radiated from a location distant from the subject. In this case, however, it is necessary to increase the irradiation intensity to irradiate the irradiation subject with desired X-rays, and also, other undesired area may be irradiated, causing a leak of X-rays.

The inventors of the present invention has invented a flat-tube-type X-ray tube (hereinafter called "flat X-ray tube") shown in FIG. **5** and FIG. **6**. This X-ray tube has a main body which is a box-like package **55** including a container portion **51** and a substrate **53**. The container portion **51** is formed into a box-like shape with one back plate **61** made of glass and four side plates **62** attached together. The substrate **53** is made of a radiopaque metal and is arranged at an open end of the container portion **51**. The substrate **53** located on the side of the X-ray radiation of the box-like package **55** includes an elongated slit-like opening portion **52** (with a thickness of about 2 mm, for example), and an X-ray transmission window **54** made of a titanium foil is attached to the elongated slit-like opening portion **52** from the outside of the substrate **53**.

Inside of the box-like package **55** is maintained in a high-vacuum state. On the inside of the box-like package **55**, an X-ray target **56** such as tungsten is provided to the X-ray transmission window **54** seen through the elongated slit-like opening portion **52** of the substrate **53**. Furthermore, on the inside of the box-like package **55**, a back electrode **57** is provided on an inner surface of a back plate **61**, i.e. an inner surface located on the opposite side of the X-ray transmission window **54**. Furthermore, a filament-like cathode **58**, a first control electrode **59** for drawing electrons from the filament-like cathode **58** and a second control electrode **60** for accelerating the electrons drawn by the first control electrode **59** are arranged sequentially below the back electrode **57**.

According to this X-ray tube, the electrons drawn from the filament-like cathode **58** by the first control electrode **59** are accelerated by the second control electrode **60**, and then the electrons collide with the X-ray target **56** to generate the X-rays. The X-rays generated from the X-ray target **56** by the collision of the electrons then pass through the X-ray transmission window **54** and radiated to the outside of the box-like package **55**.

The X-rays are radiated through the X-ray transmission window **54** which is limited by the elongated slit-like opening portion **52** of the substrate **53**. Thus, by setting the size of the elongated slit of the opening portion **52** to a desired size, the radiation region of the X-ray can be substantially linear so that the X-rays can spread with a slit width of the X-ray transmission window **54**. Thus, the irradiation area which is effectively large with respective to the size of the subject can be set easily with a relatively high degree of freedom, thereby providing advantageous effect which cannot be obtained from the circular X-ray tube having the narrow irradiation area. Furthermore, by setting the size and shape of the elongated slit-like opening portion **52** to a rectangular slot-like shape having a desired size, it is possible to determine the radiation region of the X-rays on the X-ray transmission window **54** from the appearance more easily than the circular X-ray transmission window **101**, thus it is relatively easy to set a path for accurately directing the X-rays to a desired location.

During the development of the flat X-ray tube shown in FIG. **5** and FIG. **6**, the inventors of the present invention have discovered a phenomenon of change in intensity of the X-rays radiated from the flat X-ray tube. In this phenomenon, when the flat X-ray tube is operated and the X-rays are radiated, the intensity of the radiated X-rays decreases with increase in the operating time but after a certain time it begins to increase again. The inventors of the present invention have studied this phenomenon, and found out further details about this unknown phenomenon and what is behind it, as explained below.

FIG. **7** shows a cross-sectional view of a flat X-ray tube proposed by the inventors of the present invention. This flat X-ray tube has a basic structure similar to that of the flat X-ray tube shown in FIG. **5** and FIG. **6**. In FIG. **7**, elements similar to those of FIG. **5** and FIG. **6** are indicated by like references to eliminate explanation thereof. In this X-ray tube, when electrons emitted from a cathode **58** collided with an X-ray target **56**, X-rays are emitted from the X-ray target **56** and are radiated outward through an X-ray transmission window **54**. According to a study by the inventors of the present invention, it was found that, during this stage, there is a phenomenon in which the electrons which had collided with the X-ray target **56** are reflected backward toward the second control electrode **60** in the box-like package **55**. FIG. **7** illustrates trajectories of the electrons which had collided with the X-ray target **56**, reflected and reached to an inner surface of the box-like package **55**. These results are obtained from the study by the inventors of the present invention and are obtained by simulating the trajectories of the electrons which had collided with the X-ray target **56** and reflected by analyzing the electric field in the box-like package **55** using a finite element method.

The inventors of the present invention have carried out further research on temporal changes in an X-ray target current relative value which correspond to the intensity of the X-rays radiated from the X-ray tube. The results are shown in FIG. **8**. According to this example, when the X-ray tube is continuously operated with an initial current value of 100%, the current value continues to decrease (hereinafter called "current degradation") until the operating time reaches to about 100 hours, and the current value is decreased to about 60% of the initial current value when the operating time had reached to about 100 hours. After that, the current value begins to increase (hereinafter called "current increase") and returned to 100% after about 2,000 hours. The intensity of the X-rays radiated from the X-ray tube changes in a manner corresponding to the temporal changes in the X-ray target current.

The inventors of the present invention predicted that the temporal changes in the X-ray target current relative value corresponding to the X-ray intensity are caused by the behavior of the reflected electrons such as those shown in FIG. **7**. As a result of further research, the inventors of the present invention had obtained the following understanding. FIG. **9** illustrates the cause of the above-mentioned current degradation which occurs during the operation of the X-ray tube. In the drawing, the electron is indicated by a reference sign "e−", and the movement of the electron is indicated by an arrow. The electron which had collided with the X-ray target **56** and reflected is collided again with the inner surface of the box-like package **55** and is reflected and moved to an inner surface, i.e. a back plate **61** having a back electrode **57**, of the box-like package **55** located on the opposite side of the substrate **53** having the X-ray transmission window **54** (i.e., the back plate **61** is charged). In FIG. **9**, the charged state of the back plate **61** is indicated by a reference sign "−" to distinguish from the above-mentioned reference sign "e−". Furthermore, the electron which had collided with the X-ray target **56** and reflected is collided with the inner surface of the box-like package **55**, causing a secondary electron to be emitted from a glass plate of the box-like package **55**. This secondary electron is moved to the back plate **61** and charges the back plate **61**. In this manner, the number of the reflected electrons and the secondary electrons moved to the back plate **61** are increased, gradually causing the electrons to be less easily emitted from the cathode **58**. As a result, the current degradation occurs, i.e. the X-ray target current decreases with the operating time.

FIG. **10** is an illustration for explaining the cause of the above-described current increase which occurs during the operation of the X-ray tube. In the drawing, the electron is indicated by a reference sign "e−", the sodium ion is indicated by a reference sign "Na+", and the movement of the electron and the sodium ion is indicated by an arrow. As described above, the number of the reflected electrons and the secondary electrons moved to the back plate **61** increases gradually but will saturate with time. Then, an effect of Na+(sodium ions), which were generated from contamination when the secondary electrons were generated due to the collision of the reflected electrons with the inner surface of the box-like package **55**, begins to appear gradually. That is, it is considered that, as these Na+ are attached to the second control electrode **60**, the first control electrode **59** and the back electrode **57**, the substantive potential of these electrodes will increase, and thus a force for drawing the electrons from the cathode **58** is increased gradually, causing the increase in the X-ray target current, i.e. the current increase described above, with the operating time.

The present invention is based on the above-described new problem which was found by analyzing the phenomenon discovered by the inventors of the present invention. Thus, an object of the present invention is to provide a flat X-ray tube which includes an electron source, a control electrode and an X-ray target and such arranged inside of a package in a high-vacuum state and which prevents a change in X-ray intensity with time.

In order to achieve the above-described object, the present invention provides, in a first aspect, an X-ray tube including: a radiopaque substrate including a slit-like window portion; an X-ray transmission window provided from a side of an outer surface of the substrate so as to close the window portion; an X-ray target provided at the window portion from a side of an inner surface of the substrate; a container portion attached to the inner surface of the substrate, an inside of the container portion being in a high vacuum state; an electron source provided to the inside of the container portion and arranged to supply electrons to the X-ray target; a first control electrode positioned between the electron source and the X-ray target inside the container portion, the first control electrode being arranged to draw electrons from the electron source; and a second control electrode positioned inside the container portion and between the first control electrode and the X-ray target, the second control electrode defining an irradiation area of an electron beam; wherein a shielding electrode is provided at the inner surface of the substrate and arranged along a longitudinal direction of the window portion.

Furthermore, the present invention provides, in a second aspect, the X-ray tube described above, wherein the shielding electrode is provided in a pair so as to sandwich the window portion, such that electrons collided with the X-ray target and reflected are prevented from reaching to an inner surface of the container portion and that discharge between the shielding electrode and the second control electrode is prevented, and wherein a distance between each of the shielding electrodes and the second control electrode is set such that an electric field formed between the shielding electrodes and the second control electrode at an operating voltage does not exceed a discharge electric field threshold of 10 kV/mm.

As explained above, according to the X-ray tube described in the first aspect, the electrons drawn from the electron source by action of the first control electrode are collided with the X-ray target within the irradiation area defined by the second control electrode. As a result, X-rays are generated from the X-ray target are radiated to outside through the X-ray transmission window. At the same time, some of the electrons collided with the X-ray target are reflected, and some of these reflected electrons travel toward the inner surface of the container portion and such if no measure is taken. However, since the X-ray tube is provided with the shielding electrode arranged on the inner surface of the substrate along the slit-like window portion having the X-ray target with which the electrons collide, the electrons reflected on the X-ray target between the shielding electrodes are absorbed by the shielding electrodes and become a part of the X-ray target current, so the electrons will not reach to the inner surface of the container portion and such. As a result, even if the X-ray tube is continuously operated, the emission of electrons from the electron source will not be unstable with time, preventing the above-mentioned current degradation and the current increase. In other words, regardless of time, the target current can be stabilized, and the X-rays of constant and uniform intensity can be radiated at all times.

As explained above, according to the X-ray tube described in the second aspect, the shielding electrode is provided in a pair so as to sandwich the slit-like window portion, and the distance between the pair of shielding electrodes, the height of the respective shielding electrodes and the distance between the shielding electrode and the second control electrode is set to be within a suitable value determined by experiments. Thus, the discharge does not occur between the shielding electrode and the second control electrode, and the electrons which had collided with the X-ray target sandwiched between the shielding electrodes and reflected will not reach to the inner surface of the container but will reach to the shielding electrode and absorbed.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross-sectional view showing an X-ray tube according to a first embodiment of the present invention and illustrating trajectories of reflected electrons in the X-ray tube;

FIG. **2** is a cross-sectional view showing a modified version of the X-ray tube of the first embodiment and illustrating trajectories of reflected electrons in the X-ray tube;

FIG. **3** is a graph showing a relationship between operating time and an X-ray target current for the X-ray tube of the first embodiment, the X-ray tube of the modified version of the first embodiment and a conventional X-ray tube developed by the inventors of the present invention;

FIG. **4** is a cross-sectional view of a convention circular X-ray tube and an X-ray radiation region thereof is illustrated schematically;

FIG. **5** is a cross-sectional view of an old model X-ray tube developed by the inventors of the present invention;

FIG. **6** is a front view of the old model X-ray tube developed by the inventors of the present invention;

FIG. **7** is a cross-sectional view showing trajectories of reflected electrons in an old model X-ray tube developed by the inventors of the present invention;

FIG. **8** is a graph showing a relationship between operating time and an X-ray target current for the old model X-ray tube developed by the inventors of the present invention;

FIG. **9** is a cross-sectional view for explaining a cause of a current degradation in the old model X-ray tube developed by the inventors of the present invention; and

FIG. **10** is a cross-sectional view for explaining a cause of a current increase in the old model X-ray tube developed by the inventors of the present invention.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

In the following, a first embodiment of the present invention is explained in reference to FIGS. **1** to **3**. An X-ray tube shown in FIG. **1** and an X-ray tube shown in FIG. **2** have the same structure except for a later-described shielding electrode. The shielding electrode of FIG. **1** and the shielding electrode of FIG. **2** are different in size. FIG. **1** and FIG. **2** show trajectories of reflected electrons obtained from a simulation by an analysis of electric field using a finite element method. FIG. **3** is a graph showing a relationship between operating time and an X-ray target relative current for X-ray tubes of the above-described two examples of the first embodiment and for an old model conventional X-ray tube developed by the inventors of the present invention.

An X-ray tube **1** according to the first embodiment shown in FIG. **1** and FIG. **2** is a flat-tube-type and includes a box-like package **2** as a main body. This box-like package **2** includes a radiopaque substrate **4** provided with a window portion **3**, and a box-like container portion **5** attached to a side of an inner surface of the radiopaque substrate **4**. Inside of the box-like package **2** is highly evacuated to maintain a high vacuum state. The radiopaque substrate **4** is a rectangular plate made of a radiopaque alloy 426, and the box-like container portion **5** is formed by assembling a back plate **6** and a side plate **7** made of a soda-lime glass. The radiopaque Alloy 426 is alloy of 42% Ni, 6% Cr and remnant Fe, for example, and has substantially the same coefficient of thermal expansion with the soda-lime glass.

As shown in FIG. **1** and FIG. **2**, the window portion **3** which is a slit-like opening portion is formed at a center of the radiopaque substrate **4** to radiate the X-rays to outside. Herein, the term "slit-like" means a shape in general having two directions, namely a longitudinal direction and a lateral (i.e. short-side) direction, and specifically, it means an elongated shape such as a rectangular shape or an oval shape. In this embodiment, the slit-like shape is an elongated rectangular shape. An X-ray transmission window **8** made of a titanium foil which is larger than the window portion **3** is adhered to the window portion **3** so as to close the window portion **3**. On the inside of the box-like package **2**, a tungsten film is deposited on an inner surface of the radiopaque substrate **4** around the window portion **3** and on an inner surface of the X-ray transmission window **8** (i.e. the titanium foil) seen from the window portion **3**, thereby forming an X-ray target **9**. The X-ray target **9** is metal which emits X-rays upon collision of an electron with the X-ray target **9**. The X-ray target **9** may be made of metal other than tungsten, such as molybdenum.

In the following, configuration of an electrode in the box-like package **2** is explained. As shown in FIG. **1** and FIG. **2**, on the inside of the box-like package **2**, a back electrode **10** is provided on an inner surface of the box-like container portion **5** on the opposite side of the X-ray transmission window **8** (i.e. an inner surface of the back plate **6** which is parallel to the radiopaque substrate **4**). A linear cathode **11** as an electron source is positioned right above the back electrode **10**. The linear cathode **11** is formed by covering a surface of a core wire made of tungsten or the like with carbonate, and can emit thermal electrons when the core wire is heated by applying current.

A first control electrode **12** for drawing electrons from the linear cathode **11** is provided above the linear cathode **11**. The first control electrode **12** includes a slit-like opening portion **13**, and a mesh is provided in the slit-like opening portion **13**.

A second control electrode **14** defining the irradiation area of an electron beam is provided above the first control electrode **12**. The second control electrode **14** is a box-like electrode member including a rectangular center plate **15** and a plate-body **16** surrounding the rectangular center plate **15**. The second control electrode **14** is provided on the inner surface of the back plate **6** so as to surround the back electrode **10**, the linear cathode **11** and the first control electrode **12**. The rectangular center plate **15** of the second control electrode **14** includes a slit-like opening portion **17** formed at a location corresponding to the linear cathode **11**. The width of this slit-like opening portion **17** is smaller than the width of the slit-like opening portion **13** of the first control electrode **12**, and the opening portion **17** includes a mesh as with the slit-like opening portion **13** of the first control electrode **12**.

The radiopaque substrate **4** includes a shielding electrode **20** extending from the inner surface of the radiopaque substrate **4** and arranged in parallel with the longitudinal direction of the window portion **3** of the radiopaque substrate **4**. The shielding electrode **20** may be provided as a pair of plate-like electrode members and is arranged such that there is an electrical continuity between the shielding electrode **20** and the X-ray target **9**. The pair of shielding electrodes **20**, **20** is formed into a rectangular shape and arranged along the longitudinal direction of the slit-like opening portion **13** of the first control electrode **12** or along the longitudinal direction of the slit-like opening portion **17** of the second control electrode **14**. Also, the pair of shielding electrodes **20**, **20** is fixed on the side of the radiopaque substrate **4** by welding from the side of the inner surface of the radiopaque substrate **4** so as to be parallel to each other along the longitudinal edge of the window portion **3**.

As explained below, the dimension in the height direction (i.e. height), h, of the pair of shielding electrodes **20**, **20** perpendicular to the radiopaque substrate **4** is set based on the inventor's knowledge and the results of the simulation of electron trajectories by an analysis of electric field using a finite element method as well as the experimental results. That is, the height, h, of the pair of shielding electrodes **20**, **20** is set such that the electric discharge does not occur between the second control electrode **14** and the pair of shielding electrodes **20**, **20**, and that trajectories of the electrons collided with the X-ray target **9** and reflected between the pair of shielding electrodes **20**, **20** are blocked to prevent the reflected electrons from reaching to the side plate **7** of the slit-like container portion **5**.

FIG. **1** shows an example of the shielding electrode **20** having the height, h, of 2.5 mm, and in this case, the distance D between the shielding electrode **20** and the second control electrode **14** is 3 mm. FIG. **2** shows another example of the shielding electrode **20** having the height, h, of 4.0 mm, and in this case, the distance D between the shielding electrode **20** and the second control electrode **14** is 1.5 mm. That is, the distance between the radiopaque substrate **4** and the second control electrode is set to be 5.5 mm. As with the example shown in FIG. **1**, at least, when the height, h, is equal to or greater than 2.5 mm, the number of electrons reaching to the side plate **7** of the radiopaque container portion **5** is decreased, and the decrease in change in the X-ray target current begin to appear. Although not shown, when the height is h=3.5 mm, the number of electrons reaching to the side plate **7** of the radiopaque container **5** is further decreased. Moreover, as with the example shown in FIG. **2**, when the height, h, is equal to or greater than 4.0 mm, then almost no reflected electrons will reach to the side plate **7**, and thus the current degradation and the current increase described above are no longer observed.

Furthermore, according to the inventor's knowledge, in order to prevent the discharge between the shielding electrode **20** and the second control electrode **14**, the actual distance between the shielding electrode **20** and the second control electrode **14** is preferably at least 1 mm as with the examples shown in FIG. **1** and FIG. **2**, when the potential difference between the X-ray target **9** and the second control electrode **14** of the X-ray tube **1** is about a few kV. For a general evacuated tube, a threshold electric field of the discharge between the electrodes is considered to be 10 kV/mm. Thus, in the present embodiment, for the sake of safety, the distance between the shielding electrode **20** and the second control electrode **14** is set to be 1 mm or more, which is the condition which can prevent the discharge even if the operating voltage is twice the operating voltage 5 kV used in this embodiment.

FIG. **3** is a graph showing a relationship between the operating time and the X-ray target relative current value for the X-ray tube (h=2.5 mm) of the embodiment of FIG. **1**, the X-ray tube (h=4.0 mm) of the embodiment shown in FIG. **2**, and an old model conventional X-ray tube (h=0 mm) developed by the inventors of the present invention. As can be seen from this graph, according to the old model X-ray tube (h=0 mm) developed by the inventors, as already explained in reference to FIG. **8**, the X-ray target current changed largely with time, in which the maximum current degradation to 60% is observed, and after that the current increase is observed, and the X-ray target current returned to 100%. In contrast, according to the X-ray tube (h=2.5 mm) of the embodiment shown in FIG. **1**, the process of the current degradation is slower and the current increase occurs more rapidly compared to the old model X-ray tube. That is, in the X-ray tube of FIG. **1** the X-ray target current value of 80% is maintained after a lapse of about 60 hours, at which time the X-ray target current value of the old motel X-ray tube had reached to about 60%, i.e. its lowest value. Also, in the X-ray tube of FIG. **1**, the current increase after the lowest value was observed is more rapid compared to the old model X-ray tube. Moreover, according to the X-ray tube (h=4.0 mm) of the embodiment shown in FIG. **2**, no current degradation was observed until a lapse of about 60 hours, at which time the X-ray target current value of the old motel X-ray tube had reached to about 60%, and after that, although a slight current degradation was observed, the maximum current degradation was to about 90%. The current degradation of such level occurs after a lapse of 100 hours, but the current degradation state does not continue thereafter, and the current value returns rapidly to the original current value.

As described above, according to the X-ray tube **1** of the present invention, the electrons drawn from the cathode **11** due to the action of first control electrode **12** are controlled to be within a predetermined irradiation area by the second control electrode **14** and collide with the X-ray target **9** between the pair of shielding electrodes **20**, **20**. As a result, the

X-rays are emitted from the X-ray target **9** to outside from the X-ray transmission window **8**. At the same time, some of the electrons collided with the X-ray target **9** are reflected, and some of these reflected electrons travel toward the side plate **7** of the box-like container portion **5** and such, if no measure is taken. However, since the X-ray tube **1** is provided with the shielding electrodes **20** arranged on the inner surface of the radiopaque substrate **4** so as to surround the window portion **3** having the X-ray target **9** with which the electrons collide, the electrons reflected on the X-ray target **9** between the shielding electrodes **20**, **20** will be absorbed by the shielding electrodes **20** and become a part of the X-ray target current. Thus, the reflected electrons will not reach to the inner surface of the box-like container portion **5** and such. Consequently, even if the X-ray tube **1** is continuously operated, the emission of electrons from the cathode **11** will not be unstable with time as described above. Thus, the above-mentioned current degradation and the current increase will not occur, and thus the target current is stabilized, and the constant X-ray can be radiated at all times.

Furthermore, according to the X-ray tube **1** of this embodiment, since the X-ray target **9** is formed of the deposited film made of an element with large atomic number such as tungsten, many electrons collided with this X-ray target **9** will become the reflected electrons. However, since the shielding electrodes **20**, **20** which are provided so as to sandwich the X-ray target **9** are made of the same metal with the radiopaque substrate **4** and are integrally formed with the radiopaque substrate **4**, the reflected electrons can be captured by the shielding electrodes **20** which are electrically one with the radiopaque substrate **4** and the X-ray target **9**.

In a general X-ray tube, since an X-ray transmission window provided to a window portion of a substrate is made of a metal foil with low strength, there is a possibility of an accident in which the foil is broken and the vacuum state of a package is lost. Regarding this point, according to the X-ray tube **1** of the present embodiment, the shielding electrodes **20** which are made of the same metal as the radiopaque substrate **4** are fixed to the radiopaque substrate **4** by welding such that the shielding electrodes **20** are located on both sides of the X-ray transmission window **8** provided to the window portion **3** so as to be in parallel along the longitudinal direction. Thus, the strength of the X-ray transmission window **8** is improved, thereby decreasing the chance of twist or deformation of the radiopaque substrate **4** and preventing the leak accident due to the breakage of the metal foil.

Preferably, the first control electrode **12**, the second control electrode **14** and the shielding electrode **20** are made of the alloy 426 as with the radiopaque substrate **4** to give substantially the same thermal expansion coefficient with the box-like container portion **5** made of a soda-lime glass. In the case where the material of the box-like container portion **5** is a glass plate other than the soda-lime glass, then the radiopaque substrate **4**, the first control electrode **12**, the second control electrode **14** and the shielding electrode **20** may be made of other metal plate to give substantially the same thermal expansion coefficient with the box-like container portion **5**.

The embodiment described herein is only representative of the present invention, and the present invention is not limited to this. That is, the present invention can be modified and implemented in various ways without departing from the gist of the present invention.

REFERENCE SIGN LIST

1 X-ray tube
2 box-like package
3 window portion
4 radiopaque substrate
5 box-like container portion
8 X-ray transmission window
9 X-ray target
11 cathode (electron source)
12 first control electrode
14 second control electrode
20 shielding electrode

The invention claimed is:

1. An X-ray tube comprising:
- a radiopaque substrate including a slit-like window portion;
- an X-ray transmission window provided from a side of an outer surface of the radiopaque substrate so as to close the slit-like window portion;
- an X-ray target provided at the slit-like window portion from a side of an inner surface of the radiopaque substrate;
- a container portion attached to the inner surface of the radiopaque substrate, an inside of the container portion being in a high vacuum state;
- an electron source provided to the inside of the container portion and arranged to supply electrons to the X-ray target;
- a first control electrode positioned between the electron source and the X-ray target inside the container portion, the first control electrode being arranged to draw electrons from the electron source;
- a second control electrode positioned inside the container portion and between the first control electrode and the X-ray target, the second control electrode defining an irradiation area of an electron beam; and
- a shielding electrode is provided at the inner surface of the radiopaque substrate and arranged along a longitudinal direction of the slit-like window portion.

2. The X-ray tube according to claim **1**,
- wherein the shielding electrode is provided in a pair of shielding electrodes so as to sandwich the slit-like window portion, such that electrons collided with the X-ray target and reflected are prevented from reaching to an inner surface of the container portion and that discharge between the pair of shielding electrodes and the second control electrode is prevented, and
- wherein a distance between each of the pair of shielding electrodes and the second control electrode is set such that an electric field formed between the pair of shielding electrodes and the second control electrode at an operating voltage does not exceed a discharge electric field threshold of 10 kV/mm.

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